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RECTIFICATION OF MULTIFLASH RADIOGRAPHS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This short paper is intended for use in a comprehensive course in ballistic flash radiography for technicians, engineers, and scientists. This paper presumes that the reader knows what a flash radiograph is and has seen a number of multi-flash radiographs and understands the geometric concepts underlying the setup used to create them. Some knowledge of the terminology of geometric optics is helpful but not necessary, as is some experience with terminal ballistic testing (due to the nature of the examples). The paper does not use any complicated

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mathematics. It is practically oriented, giving some non-numerical examples and some helpful suggestions. After reading the paper, one should be able to graphically determine the true position of an object in space from the positions of its images on properly made multiflash radiographs. This paper has not been used in connection with a radiography course prior to its publication.

The techniques discussed in this paper are equally applicable to any multiple image stereographic projection for which the projection factors can be calculated for the image of each feature of interest.

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I. INTRODUCTION

A radiograph is an image on film of the shadows cast by objects lying between an x-ray source and the film. A flash radiograph is made using an x-ray pulse of very short duration. The x-rays are emitted from a very small volume, as close to a point source as practical. There being no convenient way to bend or reflect x-rays, nothing can be done to redirect the ones headed in the wrong direction, or to create a collimated beam as in the case of a flashlight or spotlight. Although the x-ray intensity distribution peaks in a cone of about 20 degrees, the x-rays act like light emitted from a lamp with a small filament and no reflector or diffuser, illuminating the entire volume of space surrounding it. As with visible light, individual rays follow straight lines from source to eventual absorption.

In flash radiography, the object being measured absorbs essentially all of the x-rays falling on it, while the surrounding x-rays proceed to the film, exposing it and forming a useful image. The shadow's image is bigger than the object, and all but the image of the point directly below the source is displaced radially away from this point. Compare this so-called stereographic projection in geometry (from a point) with that of the more familiar orthographic projection, where a perpendicular from the plane traces the outline of the object onto the plane (see Figure 1). Note that the two projections do not cast shadows of the same profile thru the object--the "horizon" on the object in the stereographic projection being closer to the source than that in the orthographic projection. Note also that as the source is moved further and further away from the object, the stereographic projection becomes indistinguishable from the orthographic one. This is exploited in typical radiographic ranges by placing the tubes as far away, and the film as near to, the shot line as practical, within required exposure intensitites and other constraints. Even then, however, image dimensions are typically 10% larger than those of the object.

This setup geometry would not be particularly objectionable, were it not for the frequent necessity of recording images from more than one tube. These images are overwritten in the same area on the same film. The result is called a multi-flash radiograph. Such a radiograph is usually used to produce a record from which kinematic (position and time) information about the (ballistic) event can measured. The enlargement of each image and the relative displacement of points from image to image requires data reduction to determine the true object positions before the data can be used. The process by which this is done is called rectification. Two methods for accomplishing this are described. In one, the product is an orthographic projection of the objects onto the film plane at a one-to-one scale. In the other more specialized method an enlarged version is produced. Each method has its advantages and disadvantages. Both are simple to do and lend themselves well to either graphical or computerized reduction techniques.

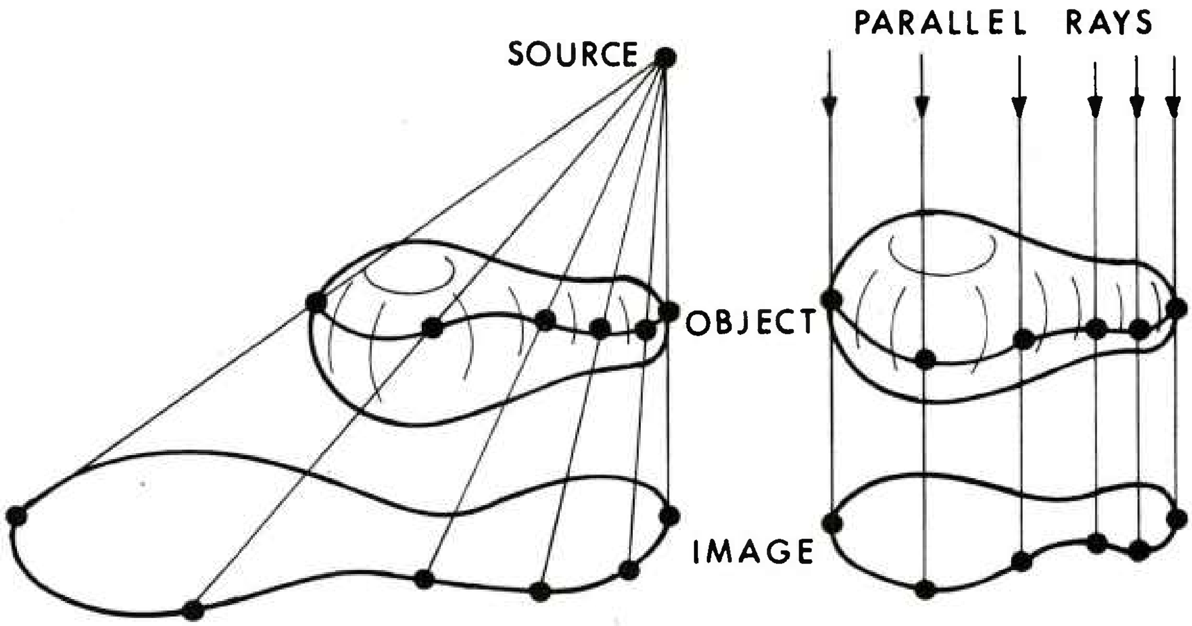

Figure 1. Stereographic (left) versus Orthographic (right) Projections of a Solid Object onto a Plane

II. RECTIFICATION TO TRUE SIZE

To illustrate the displacements that can occur when several source points project images on the same film, consider the projection geometry in Figure 2. The diamond, circle, and square lie in a common plane, and each is projected by a separate source onto the common image plane. Although their lines of symmetry divide a common line into equal lengths, the offset of the three sources and their different standoffs cause the images to be staggered and of different sizes. The diamond is projected larger than the circle, and the circle in turn is projected larger than the square. To rectify the multiple image record, one must reduce each image to its original size, and position it correctly relative to the point directly under each respective source (typically established on the film by means of fiducial wires). Let's do this for the diamond. Refer to Figure 3. Since every point in the image plane has been expanded away from the point, P, under the source, S, by a magnification factor, M, each distance can be restored by dividing by M. For each image point, measure the distance from P along a line from P thru that point, divide by M, and plot a point at this distance from P along the line.

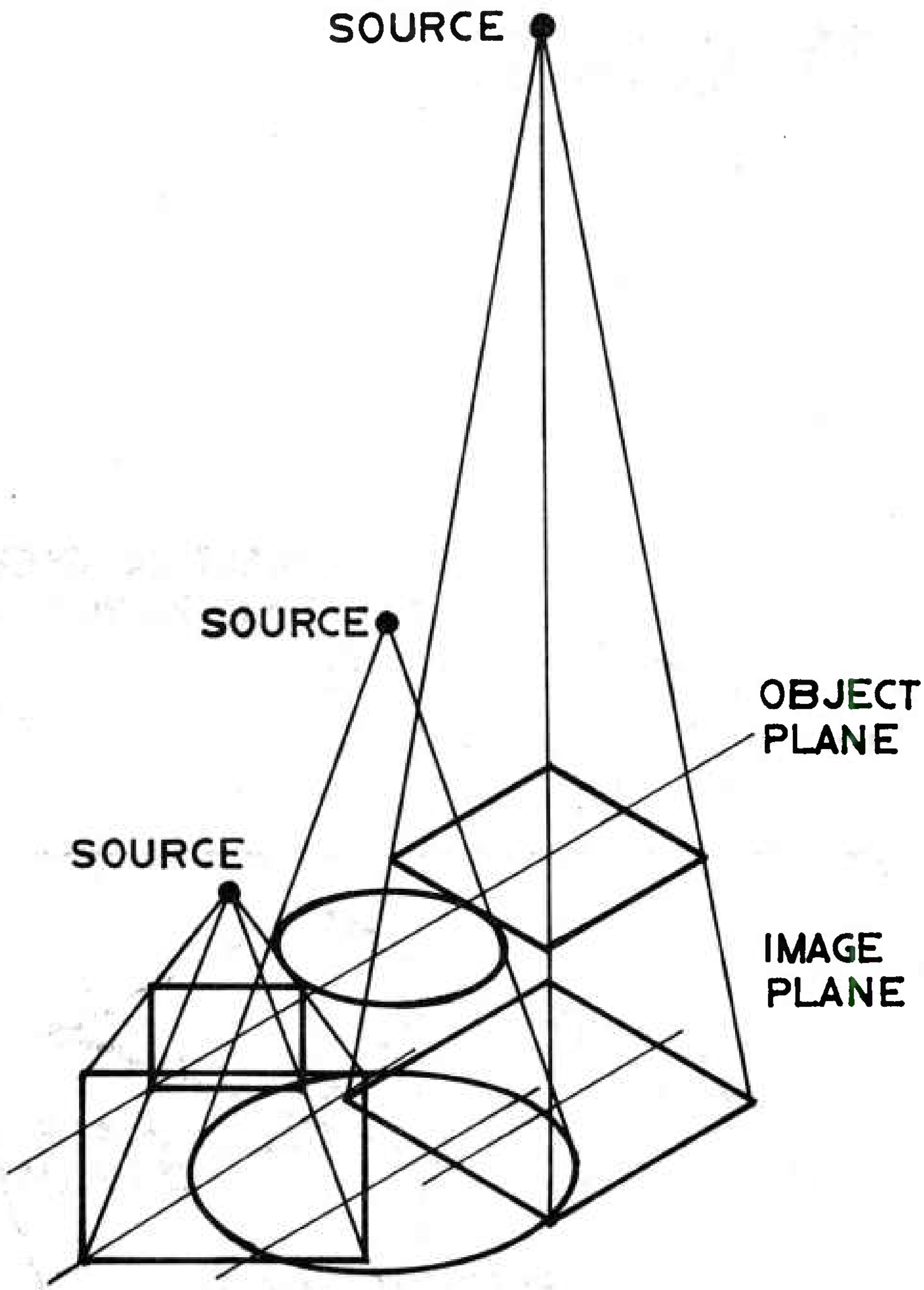

Figure 2. Relative Displacement of Images Projected from Three Source Points onto a Common Plane. (Each has a different scale factor in this illustration, and the sources are not in the same vertical or horizontal plane.)

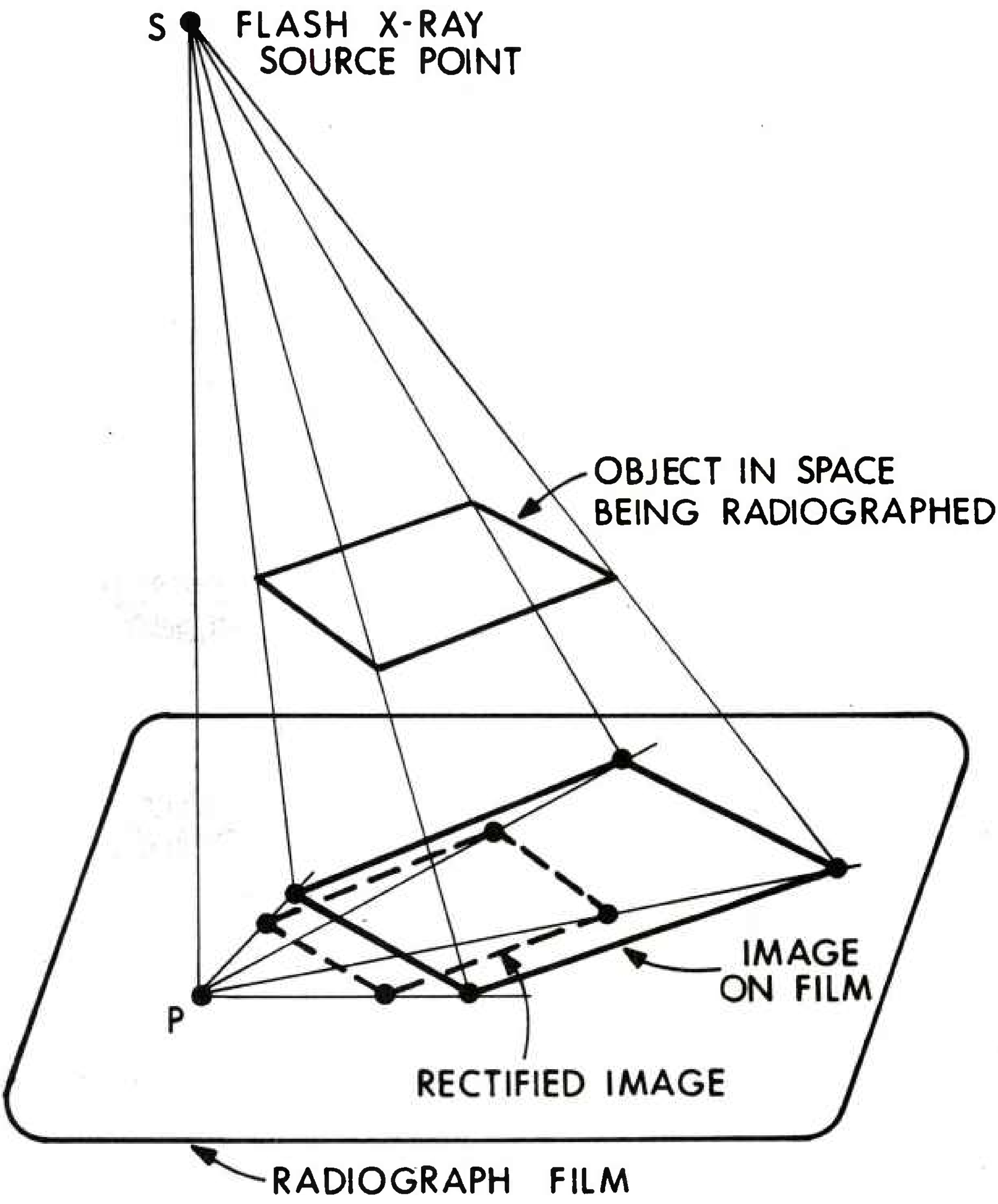

Figure 3. Rectification of a Single Image

In real life, this can be done with a drafting scale and a soft pencil directly on a radiograph, or on a sheet of tracing paper over the radiograph, or by digitizing the film, performing the appropriate calculations on a computer, and plotting the results at a convenient scale. Note that the figure shows the entire setup geometry, including the x-ray tube head and object in space, while the rectification is actually performed only on the film, dissociated entirely from the exposure setup in the test area.

Each image in turn is rectified to the size and position it would have were it projected onto the film by a conventional orthograpic projection. (The orthographic projection is familiar to us in drafting and blue print reading.) Figure 4 represents a (flat) radiograph in the image plane in Figure 2. It illustrates the graphical rectification procedure of the image from the setup shown above. Lightly drawn pencil lines radiate from each sub-source point (P1, P2, P3) thru the feature of interest on each image. The corrected point is indicated on each line by a dot, and the rectified images shown as dashed lines. As many or as few points as desired may be done, as indicated in the case of the circle.

A helpful trick, which reduces the amount of drawing actually done on the film, is to locate a scale with its zero on the sub-source point (P) and its edge passing through the image feature in question. Read off the distance to the feature, multiply by the correction factor $K = 1/M$, then put a tic mark on the film or overlay at that distance. Certain combinations of projection factors and scale divisions can be intentionally used to make this process easier. A correction factor of 0.9 and a scale subdivided into tenths eliminates the need for computing new lengths. Instead, the process is done mentally on the scale itself by subtracting 0.1 inch or centimetre for each inch or centimetre measured, 0.01 unit for each fractional tenth, and so on. The process is illustrated in Figure 5. A combination of a magnification factor of 0.875 and a scale divided into eighths or any other combination where scale factor plus subdivision add to unity are equally suitable.

III. TWO EXAMPLES

The technique discussed above can be used to best advantage where the rectified image is required to be full size and the number of points handled is relatively small. For example, it is used to determine the true horizontal and vertical angles of trajectories. To illustrate this, consider the problem encountered during the development of the pusher plate deflector. An expendable plastic device with a hole thru it to pass the projectile is aligned to the shot trajectory. When the pusher plate and obturator strike it, the pusher plate is deflected off the shot line. Changes in its geometry strongly influence the deflection angle. To find out this relationship, numerous

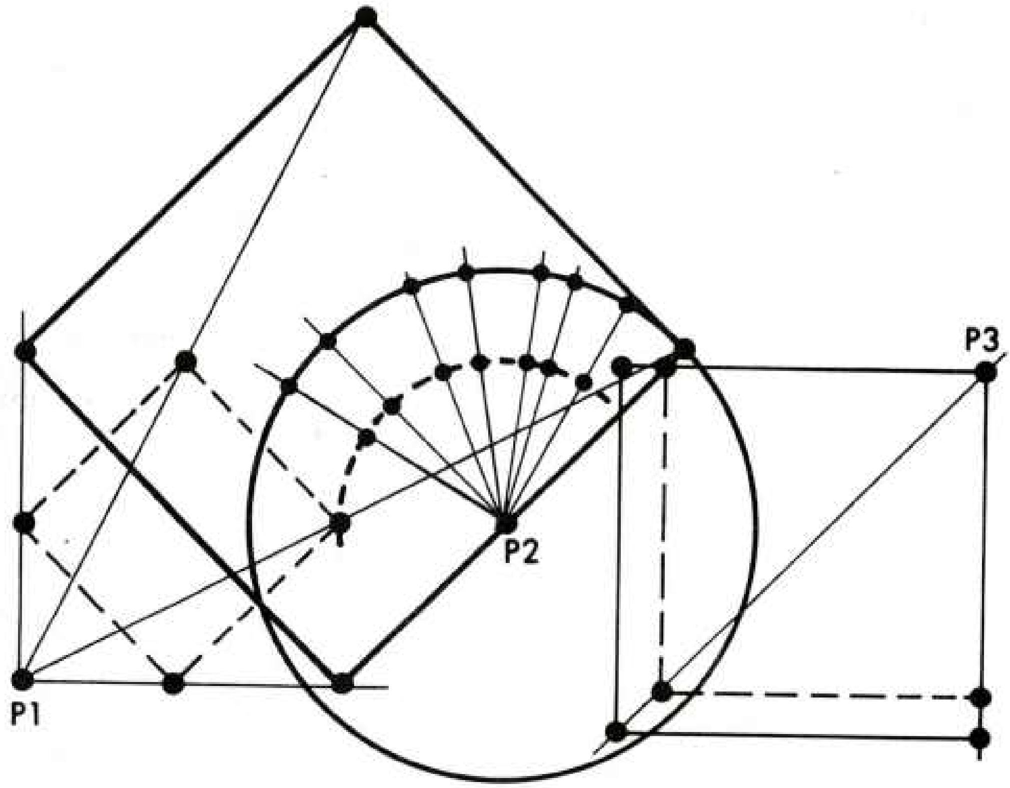

Figure 4. Graphical Construction Rectifying the Three Images on a Piece of Film in the Image Plane Shown in Figure 2

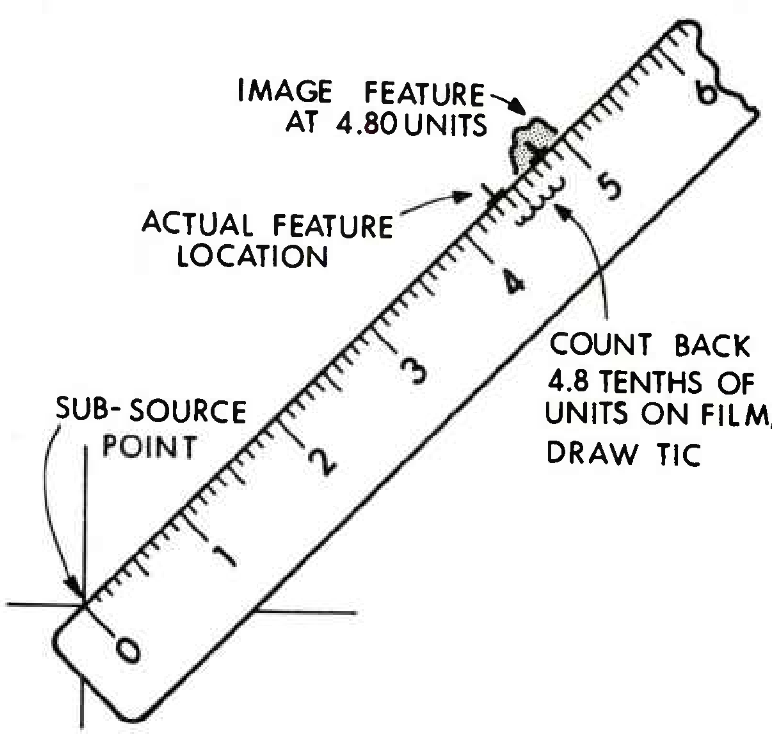

Figure 5. Sneaky Trick to Determine True Position of Point on Film Using Decimal Scale When k = 0.9

experimental deflectors were used in conjunction with required terminal ballistic tests. Determination of the path of the pusher plate was only incidental to the basic test, so the x-ray timing was not optimized for the task. Thus the position of the images on the film were frequently quite deceiving. Figure 6 illustrates a typical film image, with the rectification process used to find the true path of the pusher plate.

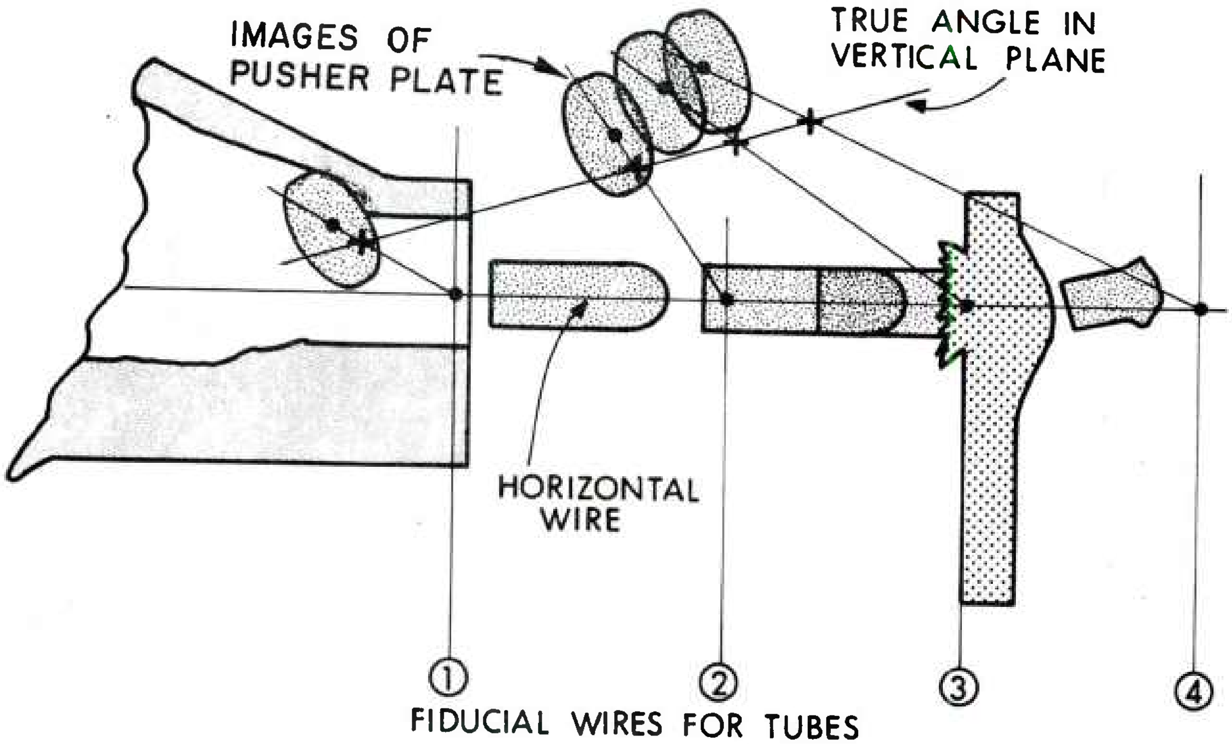

Figure 6. Determining True Projection Angle of Trajectory from Images on Film

Another use for this technique is to sort out which tube head produced which image when there is doubt. In a multiflash system with well separated heads, it is quite possible to project the successive images so that the one later in time appears uprange of an earlier image on the film. For example, this can occur when the intervals between flashes are small, as in phenomenology work, or in the event of unexpected simultaneous pulsing of several tubes. When images overlap, considerable confusion can occur. Figure 7 illustrates a case where the position of the tail of the rod is being measured at supposedly equal short intervals as the rod sinks into a target. It is suspected that tubes 2 and 3 flashed simultaneously because images I2 and I3 are not where they were expected. If this is true, the true positions of the tails should coincide for these two tubes. But just which image goes with which tube? To find out, assume that both tubes could have made either image, and plot the two true positions in each of the two alternate cases, along with the (supposedly) good positions. If I2 and I3 were projected from tubes 2 and 3 respectivley, then the true positions of the tails would be A and D respectively. Alternately, if I2 was from 3 and I3 from 2, the positions would be B and C respectively, essentially the same point in this figure. Coupled with the observation that the distance AD is not approximately one-third of the distance EF, one could conclude that tubes 2 and 3 did indeed flash simultaneously.

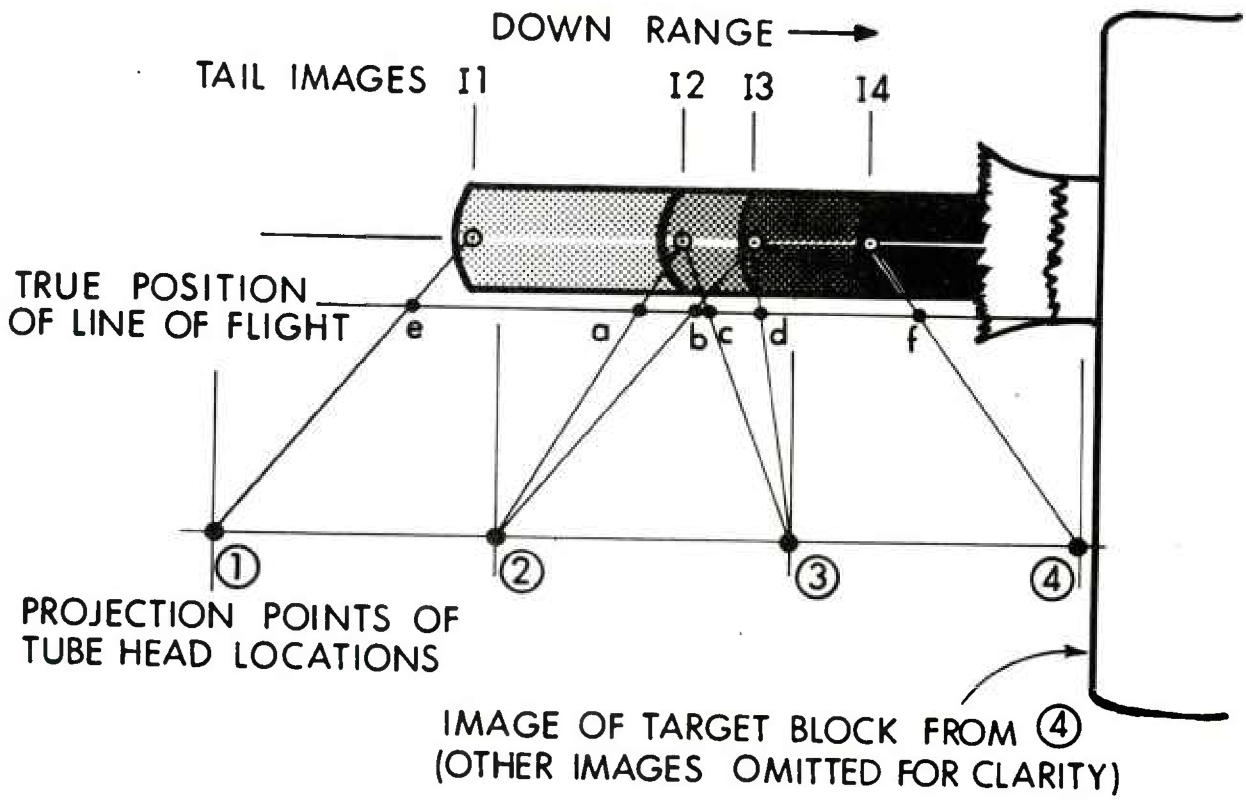

Figure 7. Testing the Alternate Hypotheses that Tubes 2 and 3 Flashed Sequentially or Simultaneously

IV. A SECOND RECTIFICATION METHOD

A strictly graphical method for rectifying images is suitable for use when all objects are in the same plane parallel to the film and the magnification factor is the same for each image. This second method takes advantage of the fact that each independent image is just a magnified view of the items in its object plane.

In Figure 8, two separate heads are projecting portions of an imaginary grid representing the range coordinate system onto the film plane below. Each grid square in the image is enlarged by the magnification factor M. Viewed relative to P1, everything from the first head maintains its same relative position, and is just magnified uniformly. The same is true for the image projected by the second head. However, the distances between a point in the first area and another point in the second area vary in a seemingly complex fashion. For example, though the distance from P1 to P2 is the same in object and image, the distance between U′ and V′ is much smaller than actually is the case for the object points U and V. Conversely, the image distance is increased between points on opposite sides of their respective sources.

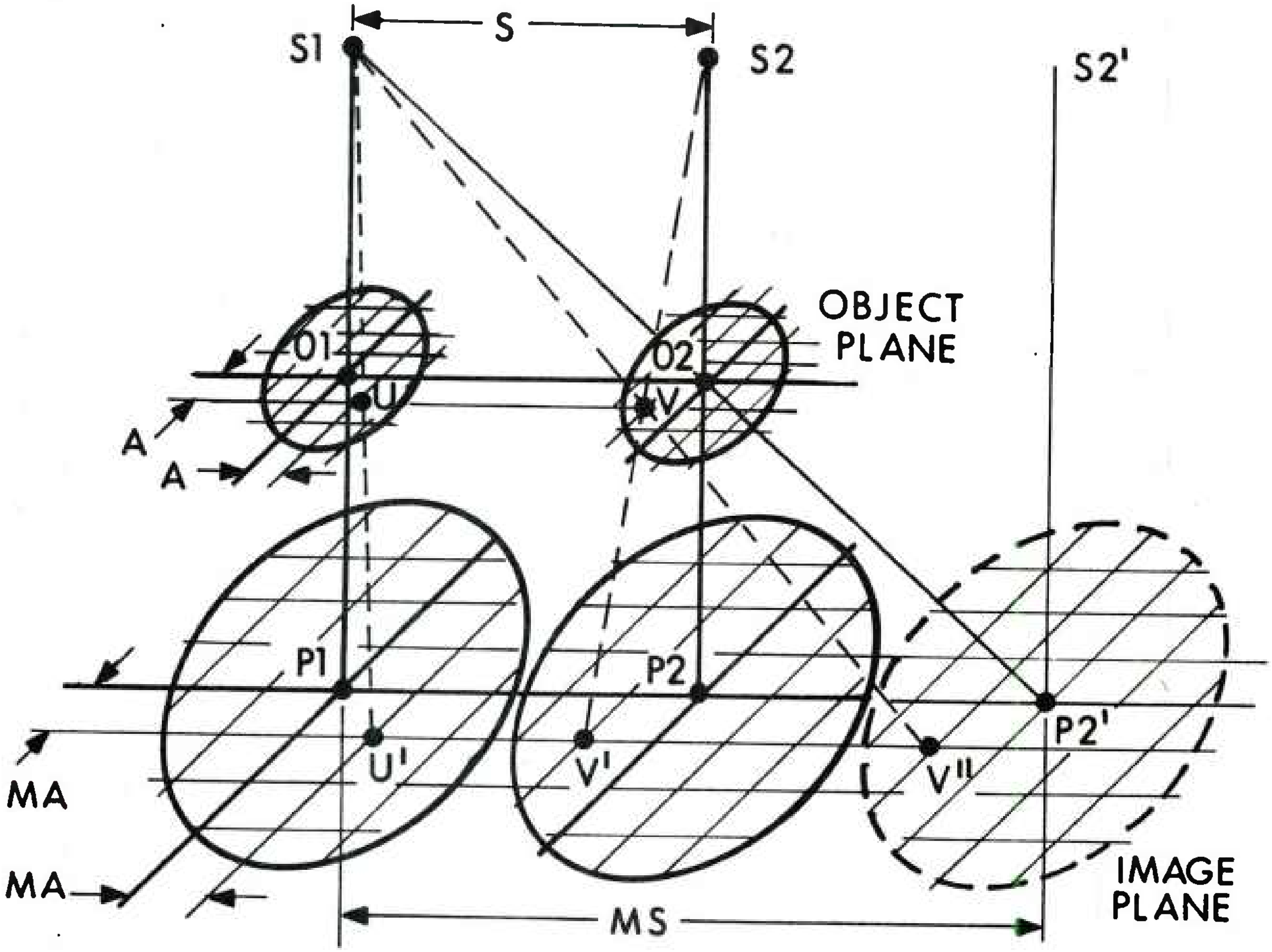

Figure 8. Relationship Between Real and Virtual Source Point Locations in Three Dimensions when Graphically Rectifying Multi-flash Radiographs

If the second image area were moved so that it was centered on the point P2 where O2 would be projected on the image plane by the first tube, then everything in the displaced image would be in its proper place relative to P1, just magnified by the factor M. To illustrate, the distance U'V' is just M times the distance UV. The light dashed lines from P1 thru U and V show the effect of this transformation.

A convenient way of understanding this is to imagine that you have been given the task of producing a drawing of everything in the object plane, scaled up by a factor M. You know that the separation of the tube heads must be increased from S by a factor M, and so you plot these two points at the increased scale on a blank piece of paper of the appropriate size. Then you begin the odious task of drawing a magnified version of everything around O1 in the object plane. Next you do the same for the region around O2, but centered around the second point representing the scaled-up location of the second tube, a distance M times S from the first. You continue measuring the images and plotting the results until you suddenly realize that everything in the first image on the radiograph is already at the appropriate scale. A better approach immediately becomes obvious: cut out the region around P1 and paste it to the required drawing centered at the first scaled-up tube location. Proceed to cut out and paste the region around P2 centered on the second scaled point (and appropriately oriented), and so on for each tube, until the job is done.

The drawback to this approach is that the images on real radiographs are horribly overwritten, so that individual images cannot be neatly separated. This is dealt with by tracing the desired features from each flash onto a master overlay on tracing paper or similar medium. First, lay out the scaled-up separation of the tube heads on the overlay, along with a suitable angular reference such as a fiducial wire. Then center and orient the overlay over the image point directly under the first tube location and trace the desired features. Move the tracing paper to center the second scaled tube head location over the second sub-source point and orient the tracing appropriately. Do likewise for each tube head.

This method is very suitable for preparing report illustrations. The resulting outline drawings produce very good copy quality under the most unfavorable reproduction conditions, while tremendous care is required to produce even marginally acceptable visual material from even the best quality radiographs. Information is conveyed quickly and easily in the tracings of the feature outlines, and at the same time, extraneous material such as multiple shadows, images of breakscreens, strands of wire, debris, and defects in the film are all excluded.

The only drawback to this second method is the increased scale of the drawings. Where it is desired to measure a considerable quantity of material directly from a rectified sketch of this nature, it is useful to prepare a ruler graduated to this increased scale. In the absence of access to a copy camera (where a real ruler can be photographed at any increased scale), one can easily do the job graphically using similar triangles as shown in Figure 9. To avoid lots of work, use a technique familiar to surveyors or draftsmen. Graduate only the major divisions, then subdivide a single division in the opposite direction beyond zero to whatever degree of fineness is required. Distances are measured by placing the appropriate major division on one feature and adding the distance from zero to the fine graduation that lines up with the other feature. A clear flat scale graduated on the face touching the film is the best arrangement.

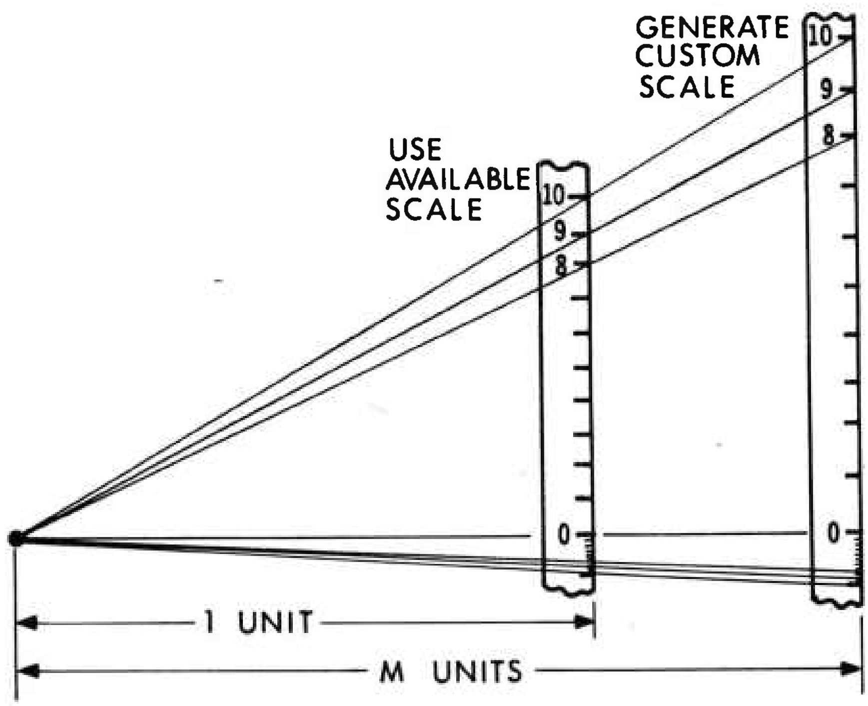

Figure 9. Generating a Custom Scale for Reading Magnified Images

In closing, it should be noted that rectification of radiographic images is seldom necessary except when doing ballistic work for phenomenology, when preparing graphical material, or when troubleshooting. However, when it is necessary, the product cannot be any more accurate than the location of the fiducials on the film relative to the tube heads, or than the accuracy to which the magnification factor is known. Thus, where accurate results are required, careful measurement of the geometry of the radiographic range is necessary.

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